Vehicular Sources in Acoustic Propagation Experiments

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Abstract

One of the most important uses of acoustic propagation models lies in the area of detection and tracking of vehicles. Propagation models are used to compute transmission losses in performance prediction models and to analyze the results of past experiments. Vehicles can also provide the means for cost effective experiments to measure acoustic propagation conditions over significant ranges. In order to properly correlate the information provided by the experimental data and the propagation models, the following issues must be taken into consideration:

- The phenomenology of the vehicle noise sources must be understood and characterized.
- The vehicle's location or "ground truth" must be accurately reproduced and synchronized with the acoustic data.
- Sufficient meteorological data must be collected to support the requirements of the propagation models.

This paper treats the experimental procedures and instrumentation needed to carry out propagation experiments. Illustrative results are presented for two cases. First, a helicopter was used to measure propagation losses at a range of 1 to 10 Km. Second, a heavy diesel-powered vehicle was used to measure propagation losses in the 300 to 2200 m range.

1. Introduction

The development of acoustic propagation models has made significant advances in recent years resulting in accurate and practical propagation models such as those based on the Fast Field Program and the Parabolic Equation. Given sufficient meteorological data with

which to derive an accurate sound velocity profile, these programs model acoustic propagation losses quite accurately. Progress is also being made in the more difficult problem of modeling the effect of atmospheric turbulence on sound propagation.

A very significant sector of the uses for acoustic propagation models is in detection and tracking problems. In these systems, signals gathered by a microphone array are used to determine the location and track of a vehicle. Both air and ground vehicles are of importance in these applications. Acoustic propagation models play a very important role, being used to either predict performance under new conditions or to analyze the results of an experiment. In this paper we describe the methodology for the analysis of data involving vehicular sources and describe results obtained from two different tests: one, a long range experiment using a helicopter; the second, a mid range experiment, using a heavy, Diesel powered vehicle.

2. Approach

The essential elements necessary for the analysis of propagation data generated by vehicles are: a) a thorough understanding of the phenomenology of the vehicular sources, b) accurate positional data of the target vehicle's trajectory (ground truth data) and c) sufficient meteorological data to reconstruct the propagation conditions.

2.1 Source Phenomenology

In a test where the target vehicle is operating freely it is impractical to monitor the source strength continuously, therefore our knowledge of the source strength must be based on prior knowledge of the source's characteristics and whatever can be inferred by monitoring the observable parameters such as aspect angle or engine RPM. We will consider two types of vehicles, helicopters and heavy diesel powered vehicles.

Helicopters provide an almost ideal source for long range propagation measurements. The noise generated by the main and tail rotors is loud and periodic with a relatively low fundamental frequency. In the spectral domain, helicopter signatures are characterized as families of narrow-band spectral lines. Fundamental frequencies of 10 to 30 Hz are typical. Source levels can reach 144 dB (re 20 micro-Pa in one Hz bands). Helicopters also operate at nearly constant blade rotational speed, as can be appreciated in a spectrogram (Figure 1), where the only frequency variations are those caused by the Doppler effect as the trajectory geometry changes. Strong aspect angle dependencies exist, both in the horizontal and the vertical planes (Figure 2). The amplitude of the rotor noise will also show a velocity

dependency proportional to the 12th power of the blade-tip Mach number (Figure 2). For a full treatment of helicopter noise characteristics, see Reference 1.

Heavy Diesel-powered vehicles are easily detected at short to medium distances. Like helicopters, the spectral characteristics of vehicle noise are dominated by families of narrow-band harmonic components. Unlike helicopters, the frequency history of these components is highly variable. Rapid changes in engine RPM occur in response to operator actions, road conditions and gear changes. The amplitude of these narrow-band components is strongly dependent on engine load and RPM, as shown in Figure 3. From the sensor location, we must be content with observing only engine RPM. A good treatment of ground vehicle noise can be found in Reference 2.

2.2 Vehicle Location Data

Vehicle position data must be collected and synchronized with the acoustic data in order to measure propagation losses. In long range experiments or when the target is moving very fast, acoustic propagation delays must be accounted for.

Helicopters and other aircraft can be tracked accurately with a radar system, if available. A more cost effective approach is to obtain tracking data from an Air Traffic Control facility, if the target is equipped with an ATC Beacon transponder. Such data can be obtained by prior arrangement with the local FAA facility.

Ground targets can be tracked with an RF multilateration system, such as the Motorola Falcon Position Location System (PLS). This system is particularly convenient, since it allows tracking of multiple targets at a one Hz rate with digital data output. As an inexpensive alternative, the position of a ground target can be tracked by maintaining radio contact with one of the vehicle operators, who calls in "marks" as they go by pre-surveyed positions.

Accurate ground truth is a necessity in these kinds of propagation experiments, but it need not be an inordinate expense if the proper procedures are worked out.

2.3 Meteorological Data

Meteorological data is a critical element of the propagation measurement, since it gives us the data necessary to understand the results of our experiment.

The necessary meteorological information consists of sound velocity profiles, pressure and humidity. Sound velocity profiles are the most difficult to obtain. Traditional methods use

balloon sounding; SODAR devices are also being used at a limited number of sites. Tower measurements provide adequate data for short range experiments, and can fill the low altitude gap in the data provided by most balloon soundings.

With progress being made in the modeling on the effects of turbulence on sound propagation, there is a need for more 'fine grained' measurements of the sound velocity profile. These gaps will have to be filled by more dense and frequent measurements of the lower atmosphere.

3. Experiment Descriptions

We will discuss the results of two propagation experiments using vehicular data. In the first a helicopter was tracked from a distance of 10 Km, in the second a diesel powered vehicle was tracked to a distance of 2.2 Km.

3.1 Helicopter Test

A test using a helicopter was made following a nearly radial trajectory starting at a distance of 10 Km. The helicopter flew at a speed of 185 Km and a height of 152 m. At the point of closest approach, it came within a distance of 500 m from the sensor site. The signature recorded by the sensors was shown in the form of a spectrogram in Figure 1. The fourth harmonic was tracked automatically to extract frequency and amplitude data (Figures 4). Positional data was obtained with a radar tracking system and time-synchronized with the acoustic data. The constant speed trajectory allowed us to easily compensate for the propagation delays.

Meteorological data consisted of a balloon sounding made approximately one hour before the test (Figure 5). The Fast Field Program was used to model propagation losses as a function of range, using the sound velocity profiles as input. A two parameter model of the surface acoustic impedance was used, with 300 Rayls of surface flow resistivity and porosity of 0.25.

The results of the measured and modeled transmission losses (TL) are compared in Figure 6. Beyond a range of 4000 m the agreement between experimental and modeled data is quite good. The mean values of the TLs were very close. More important perhaps, the statistics of the variations with respect to their mean levels were also very close. It should be recognized that propagation losses will never be modeled beyond a certain level of precision and that a statistical description of propagation losses is the most realistic outcome given a limited amount of meteorological data. The statistics of signal and noise levels become

specially important in detection problems in order to predict the performance level of specific detection schemes. A study of the statistical properties of long range propagation losses appears to be a very promising area of research.

The measured TL at ranges shorter than 4000m are higher than those predicted by the FFP. Some of the difference can be due to the directivity of the helicopter noise source, which reduces the effective source level as the elevation angle increases, however this effect is smaller than the observed discrepancy. At this point, we must attribute the differences to the inaccuracy of the sound velocity profile used in the FFP relative to the actual conditions at the time of the test. This result just reinforces the importance for accurate and timely meteorological data.

3.2 Ground Vehicle Experiment.

A short to mid range experiment was made using a heavy diesel powered vehicle. The vehicle operated on a road with a nearly radial trajectory starting at a range of 300m and finishing at a range of 2200 m.

The vehicle signature as measured at the sensor location is shown in the form of a spectrogram in Figure 7. An automatic tracking program was used to extract the amplitude and frequency data corresponding to the 6th engine harmonic or Engine Firing Rate; this information is shown in Figure 8.

Lack of sound velocity profile data forced us to model the SVP as that of a 'neutral' atmosphere, that is, a profile matching the nominal atmospheric lapse rate. The neutral atmosphere profile was used as an input to the FFP, producing the TL curve shown in Figure 9, along with the measured TL. The match between the measured and modeled TLs is good at short ranges, but they start to diverge at longer ranges. However, a simplistic model which assumes spherical spreading plus a fairly high absorption term (0.0045 dB / meter) produced an excellent fit to the measured data. We hypothesized that the difference could, in part, be explained by variations in the engine RPM and/or engine load. The noise of heavy diesel powered vehicles is directly affected by engine load and RPM. An attempt was made to compensate for the effect of RPM. This is an imperfect approach, since we should compensate for both the RPM and load, however we do not know of any practical way of inferring load at long distances. The incremental sound pressure level relative to the best fitting model was plotted against the incremental frequency relative to 80 Hz. This result is shown in Figure 10, and shows a clear dependency between SPL and frequency. The SPL figures were then adjusted to a constant 80 Hz (SPL was adjusted downward if the frequency

was more than 80 Hz, upwards if it was less than 80 Hz), producing the curve shown in Figure 11. The corrected TL curve shows a better agreement with the computational models. Some of the extreme variations in TL have also been reduced as a result of the compensation procedure.

4. Conclusions

Two experiments involving a ground vehicle and an aircraft have been analyzed with the help of the Fast Field Program, one of the state of the art acoustic propagation models. By making use of meteorological data as an input to the Fast Field Program and knowledge about the source phenomenology of the vehicles, we were able to obtain a good match between the measured and predicted transmission losses. These results are encouraging and underscore the importance of thoroughly characterizing vehicular sources and of obtaining fine grained meteorological data.

The development of computational models of sound propagation have made dramatic advances in recent years, and their need becomes the driving requirement for data collection in many field experiments.

References

1. F. H. Schmitz and Y.H. Yu, "Helicopter Impulsive Noise; Theoretical and Experimental Status", NASA Technical Memo 84390, Nov. 1983

2. Richard H. Lyon, Lectures in Transportation Noise, Grozier Publishing, Cambridge MA 1973

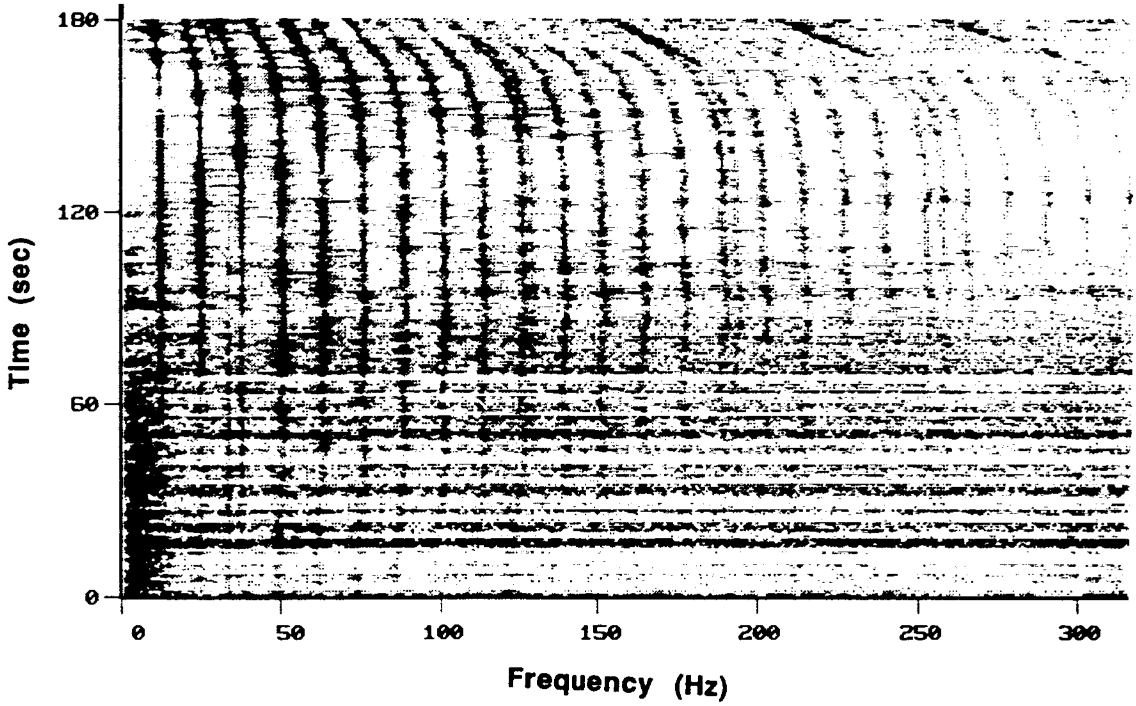

Figure 1 Spectrogram of helicopter signature, recorded during a nearly inbound-radial run.

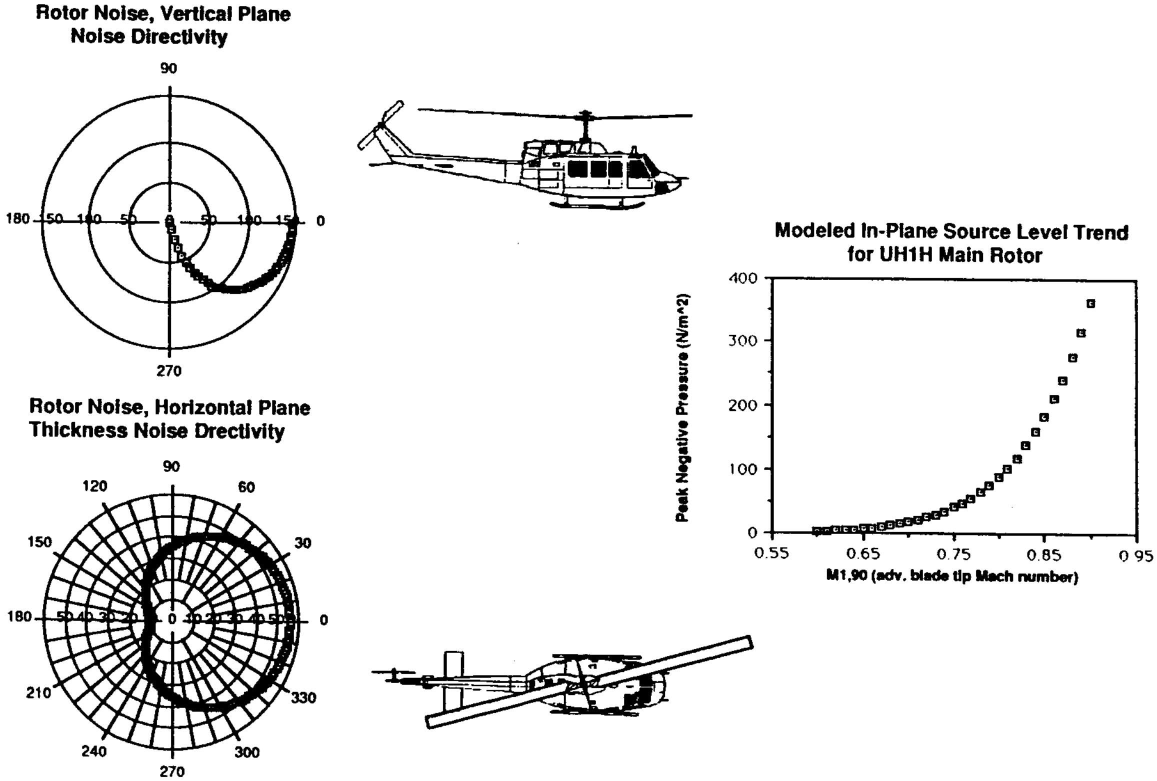

Figure 2 Helicopter noise sources are highly directional and strongly dependent on blade tip velocity (and therefore on helicopter forward speed as well).

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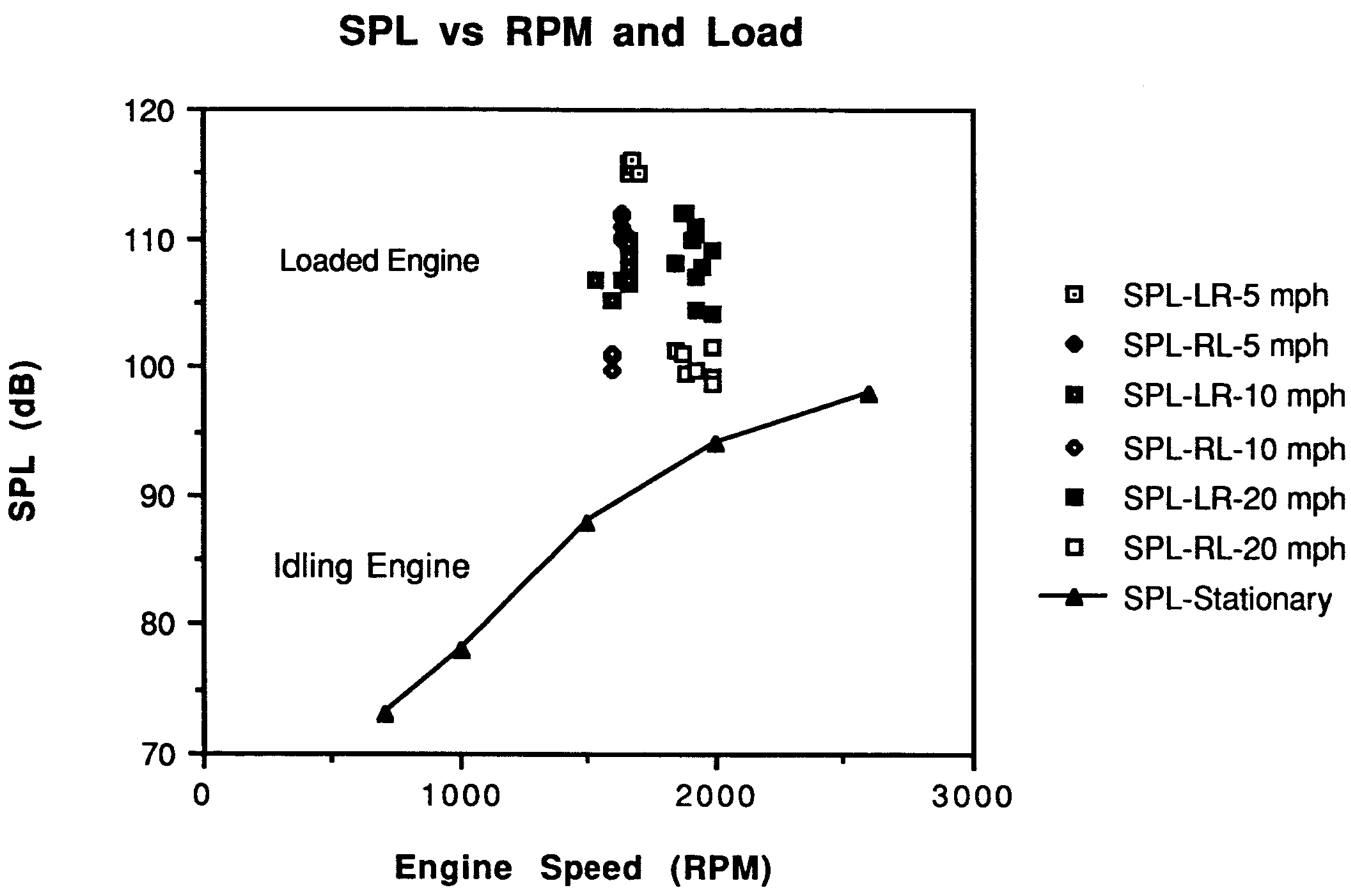


Figure 3 The noise generated by a Diesel-powered ground vehicle is strongly dependent on engine speed (RPM) and load.

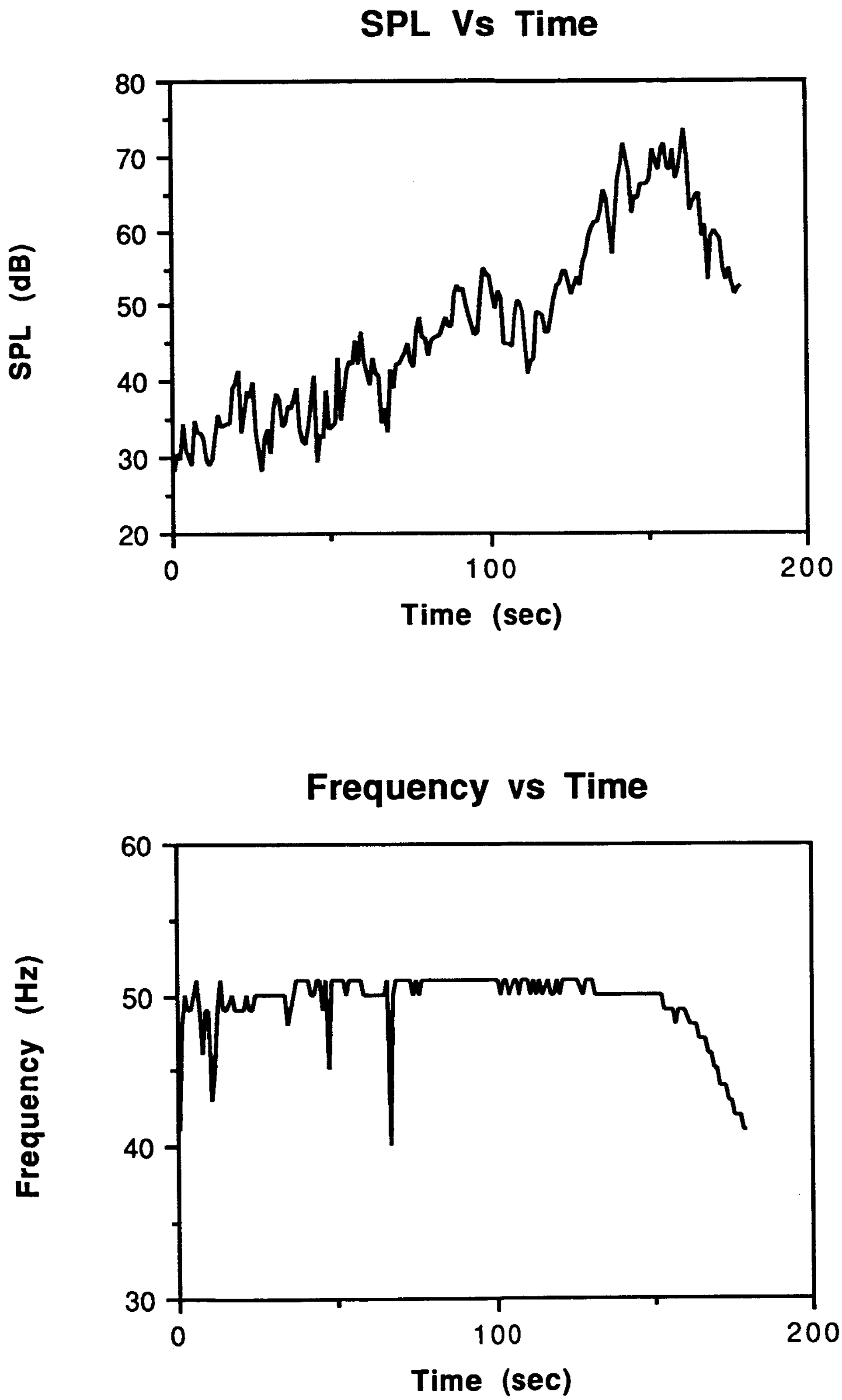


Figure 4 Amplitude and frequency of the fourth harmonic of the helicopter noise signature as a function of time.

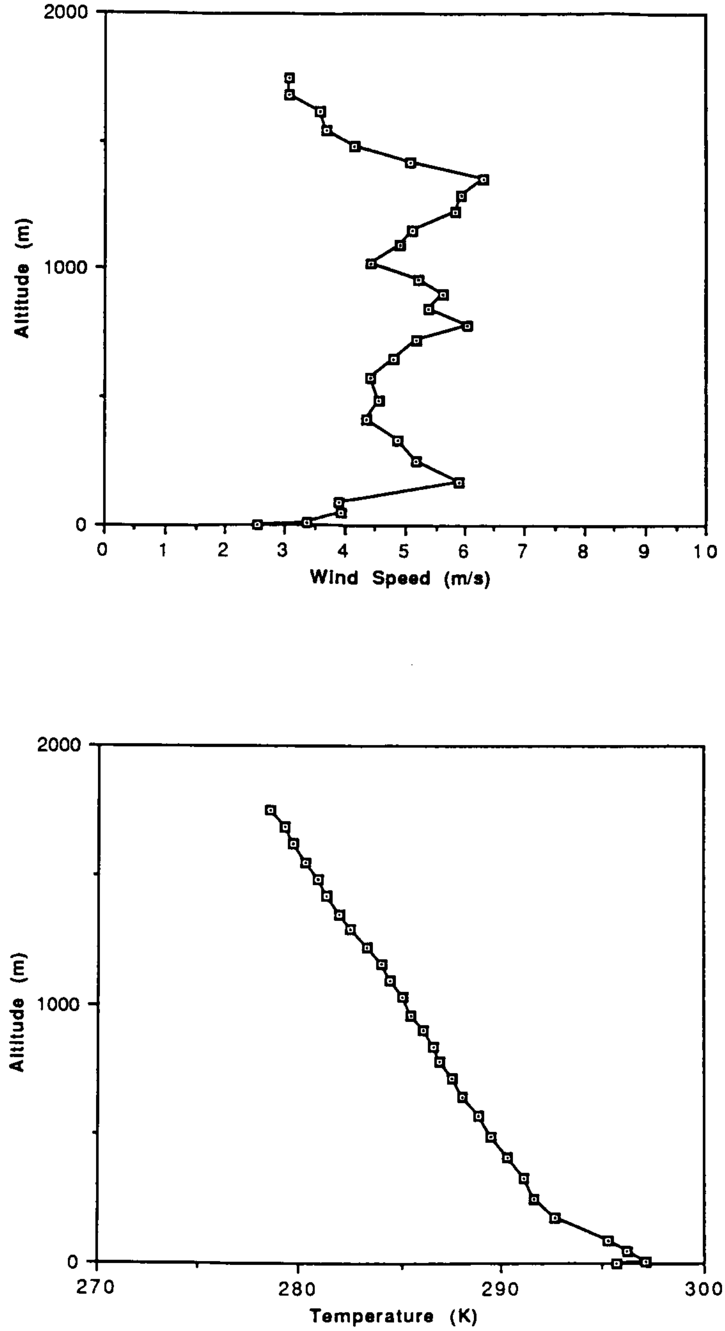
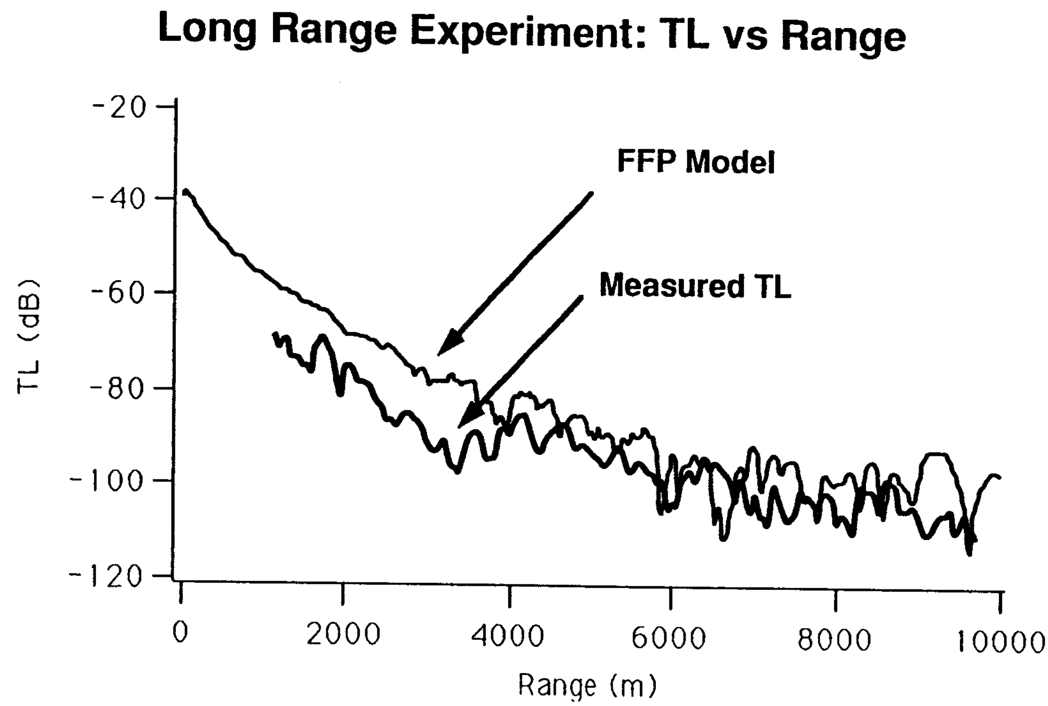


Figure 5 Profiles of temperature and wind velocity prior to the propagation experiment.



• Fast Field Program Model: Profile measured by sounding ~ 1 hour before test, 300 Rayls flow resistivity, .25 porosity

Figure 6 Measured and modeled (using the FFP) transmission losses.

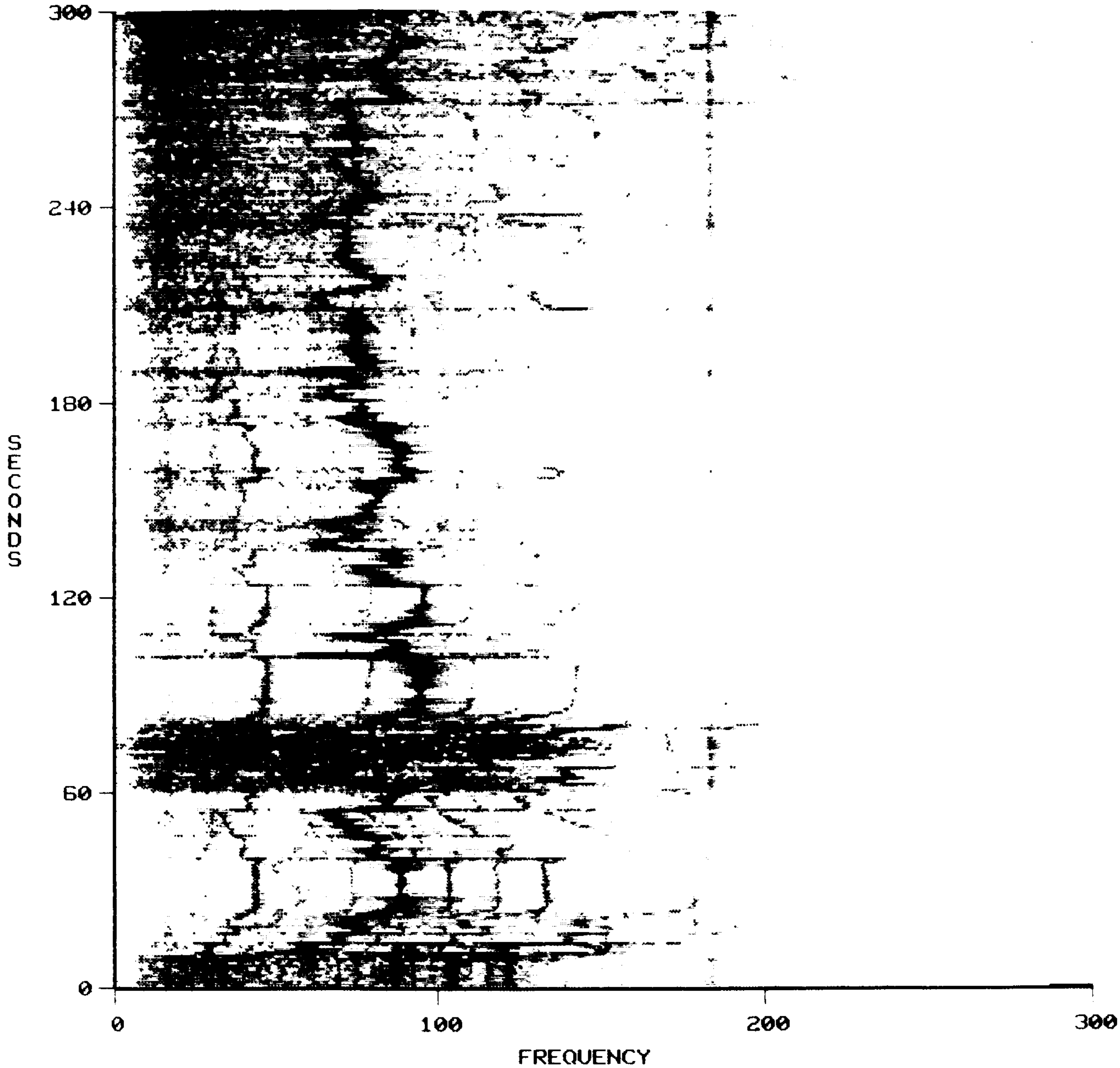


Figure 7 Spectrogram of the acoustic signature of a heavy Diesel-powered vehicle on level ground.

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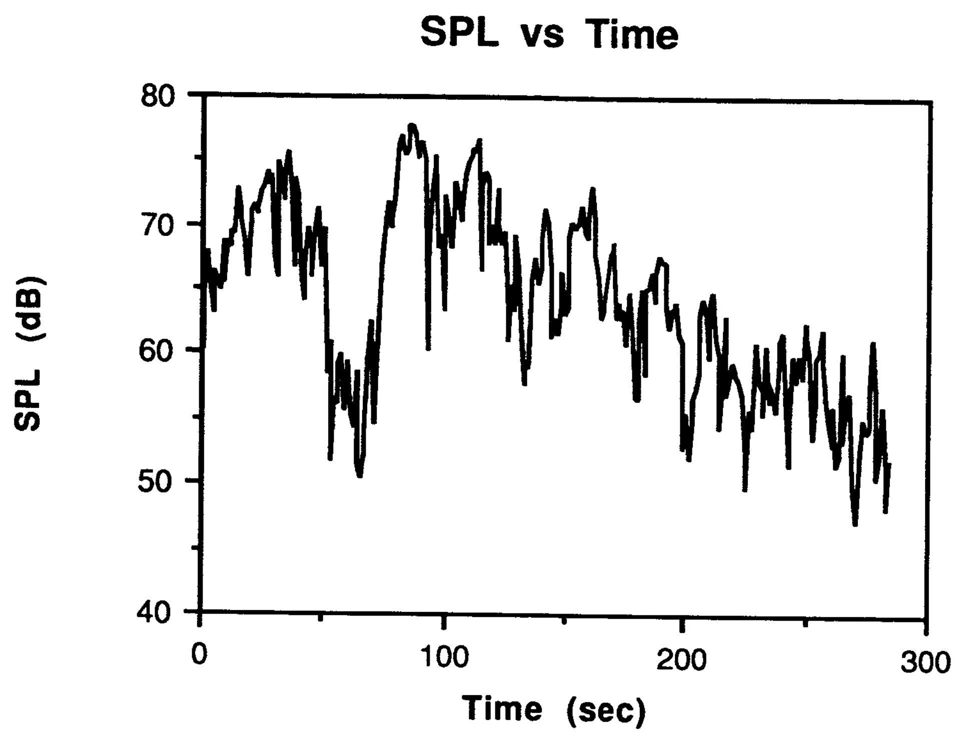

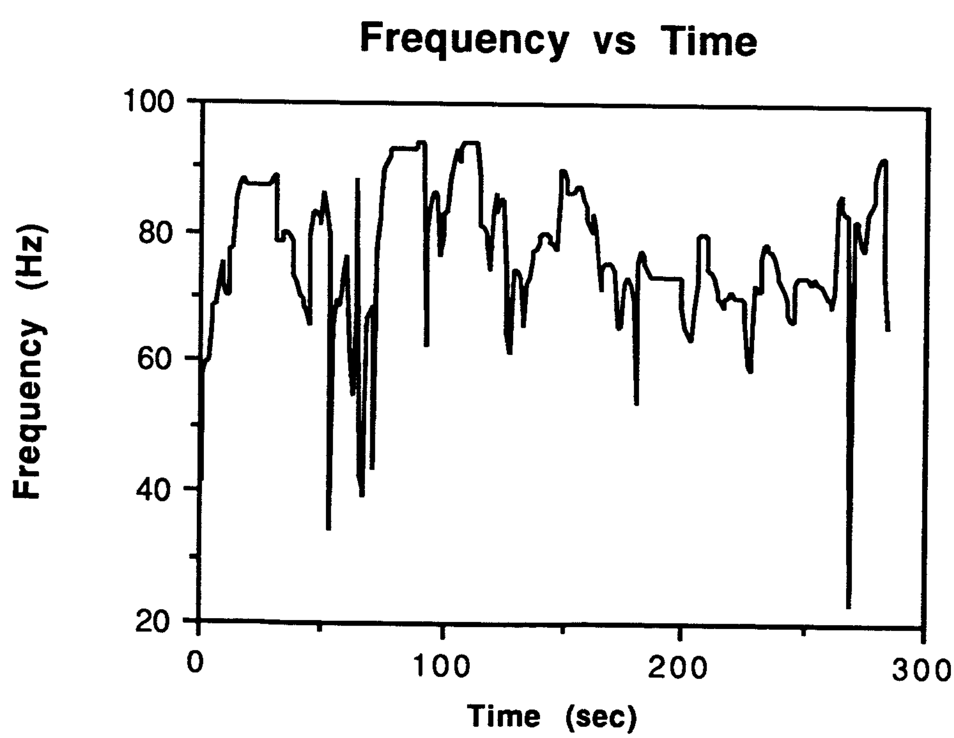

Figure 8 Amplitude and frequency of the main component of the engine noise signature as a function of time.

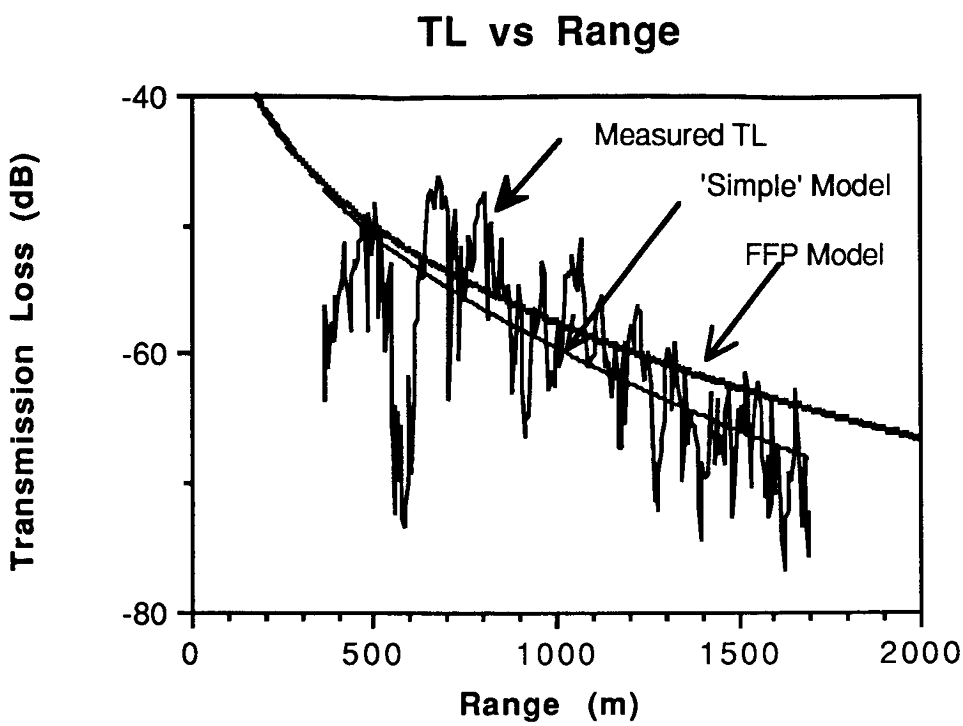

Figure 9 Measured and modeled (using the FFP) transmission losses during outward-bound run.

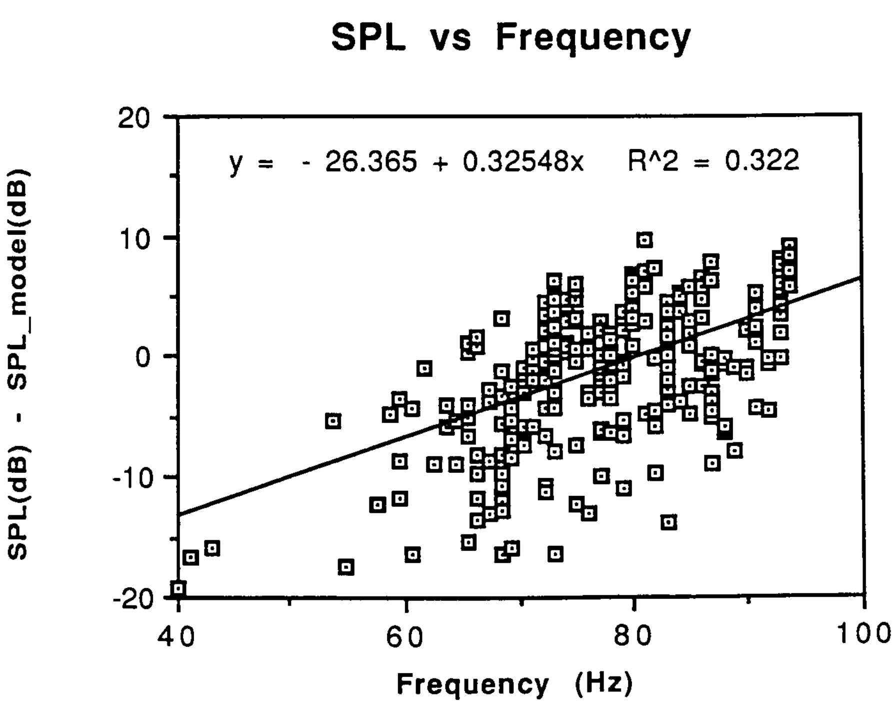

Figure 10 Measured Sound Pressure Level shows a strong dependency on engine RPM. Engine load was not directly observable in this experiment.

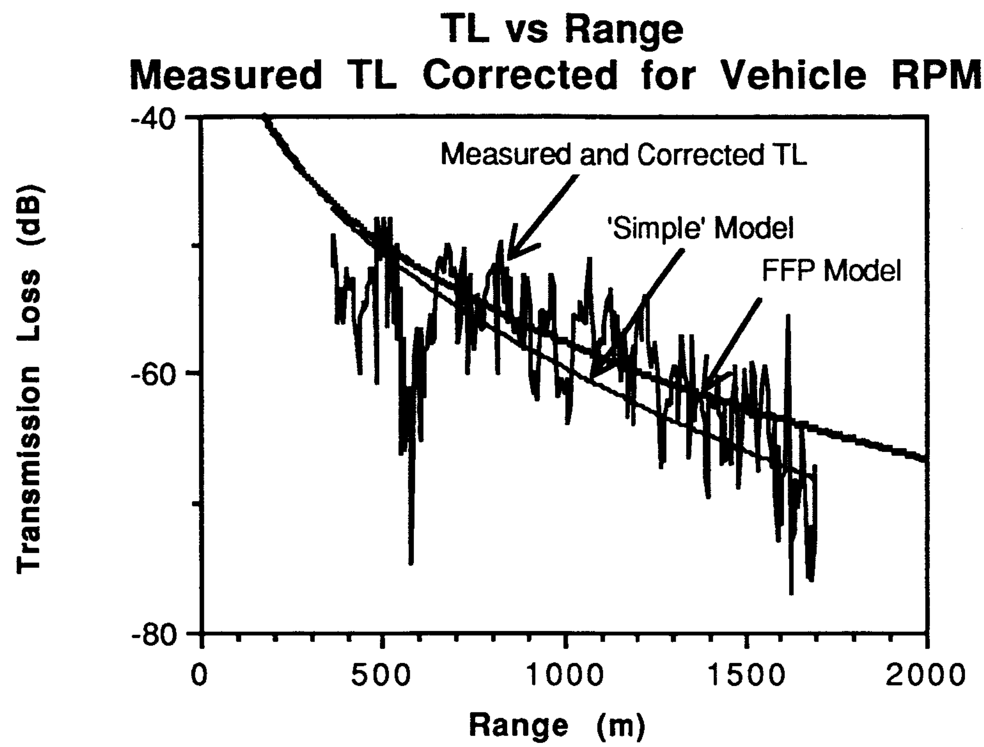

Figure 11 Measured transmission loss, after correcting for the effects of engine RPM variations.